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Liquid Cooled Heat Sink with Through Vias (LCHS)

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16. Abstract (Limit: 200 words)

This document presents the results of the Liquid Cooled Heat Sink with Through Vias (LCHS) Program. The goal of the program was to fabricate a structure with microchannels and through vias. The microchannels allow a heat dissipating liquid to flow through the structure while the vias provide an electrical pathway from the top of the structure to the bottom. A series of electrical and thermal tests were performed. The results of these tests have been interpreted. Recommendations to improve the current design was addressed.

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LIQUID COOLED HEAT SINK WITH THROUGH VIAS

Charles W. Eichelberger
J. Patrick Kusior

INTEGRATED SYSTEM ASSEMBLIES

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REPORT SUMMARY

The basic goal of the Liquid Cooled Heat Sink (LCHS) Program was to produce a component which could provide the functions of heat removal and layer to layer interconnect in 3-D electronic assemblies. Our design goals stated that the LCHS should be capable of handling a power density of 50 W/cm^2 with a 25 °C rise above ambient, it should have a through hole density of 100 holes/cm^2 and be no greater than 1.25 mm thick.

Originally, the LCHS was to be an all ceramic structure. This approach was abandoned, primarily due to the difficulty of machining 1.25 mm thick ceramic with both alternating rows of microchannels and tightly packed holes. The holes would provide an electrical pathway from top to bottom while the microchannels would allow heat dissipating water to flow through the LCHS.

It was decided that a ceramic/polymer/ceramic (C/P/C) structure would be a viable alternative to the all ceramic structure. With the C/P/C format, the ceramic would have CO_2 laser drilled holes and the polymer would be Eximer laser machined. Microchannels were Eximer laser machined into the polymer along with vias which allow for the electrical interconnection of the top and bottom ceramic plates. Thru interconnection of the top and bottom ceramic plates is accomplished by copper plating the vias; the microchannels are copper plated at the same time.

To date, the C/P/C structure has been designed and fabricated. This structure meets or exceeds all but one of the design goals. The temperature rise above ambient exceeds the 25 °C goal.

INTRODUCTION

Work on the Liquid Cooled Heat Sink (LCHS) Project began on December 7, 1992. Charles Eichelberger (Principal Investigator), J. Patrick Kusior (R&D Engineer), Joseph Doucette (Technician) and Nina Caporale (CAD Operator) are the core members of the LCHS development.

During the 1st month of development rough drafts of the LCHS were drawn. These drafts were used as guidelines for a computer aided design of the LCHS. The LCHS alignment fixture was also designed via CAD. A layout editor (LEDIT) program was used to design the photolithographic masks.

The next three months were spent ordering and evaluating materials. In early January, ALN plates with CO_2 laser drilled holes, adhesives, polymers and the photolithographic masks were ordered. The adhesives and polymers were evaluated for the better part of January and the month of February. The adhesives had to be: 1) Water Resistant, 2) Thermally stable and 3) Laser ablatable. Desirable properties for the polymers were: 1) Stress-free, 2) Transparent and 3) Laser ablatable.

The polymers and adhesives were: ULTEM (polyetherimide), LEXAN (polycarbonate) and PLEXIGLASS (acrylic) all in 30 mil sheet form; DYMAX (urethane oligimer / (meth) acrylic monomer blend - UV curable); E2 (proprietary - thermally curable); 1004 (proprietary - UV curable) and 5 Minute Epoxy (epoxy resin and polyamide - self curing). The last four are liquids which solidify upon curing. Fabrication of the LCHS prototype began in March.

METHODS AND PROCEDURES

Originally, the ceramic/polymer/ceramic structure consisted of the following: A 30 mil (0.03") thick section of polymer sandwiched between two 10 mil (0.01") thick AlN plates (we refer to one of the plates as the base plate and the other as the top plate).

Two approaches were proposed to obtain a 30 mil thick section of polymer between the two plates.

Approach #1 involved the dispensing of 35 mils worth of liquid polymer onto the base plate. The next steps would be to UV or thermally cure the polymer, then machine grind the polymer to a thickness of 30 mils. This approach failed. The polymers invariably shrunk during the curing step. As a result, the base plates were either cracked or were too warped to be ground flat.

Approach #2: Cut out a 2" x 2" section from a 30 mil sheet of polymer and adhere it to the base plate. This approach also failed. ULTEM and PLEXIGLASS did not ablate very well. LEXAN, which did ablate nicely, was ruled out because a 30 mil section would take approximately seven hours to laser process.

Beginning in April, a design change was initiated which greatly improved processability. 20 mils instead of 35 mils of polymer was dispensed onto the bottom plate. The polymer (E2) was thermally cured and ground to 15 mils. E2 is highly flexibilized and cures with low stress.

Figure #1 demonstrates the concept of the LCHS. This drawing is a side view (not to scale) parallel to the microchannels. Not shown are the electrical feedthroughs. Mounted on top of the LCHS is a heating element. Water flowing through the microchannels conducts the heat away from the heating element. If one were to replace the heating element and the aluminum block with a computer module, mount a second module on the bottom of the LCHS and then electrically connect both modules, one can easily see the advantages of this system. Two modules can communicate over a very short path length (<50 mils, the thickness of the LCHS) while simultaneously being cooled by water.

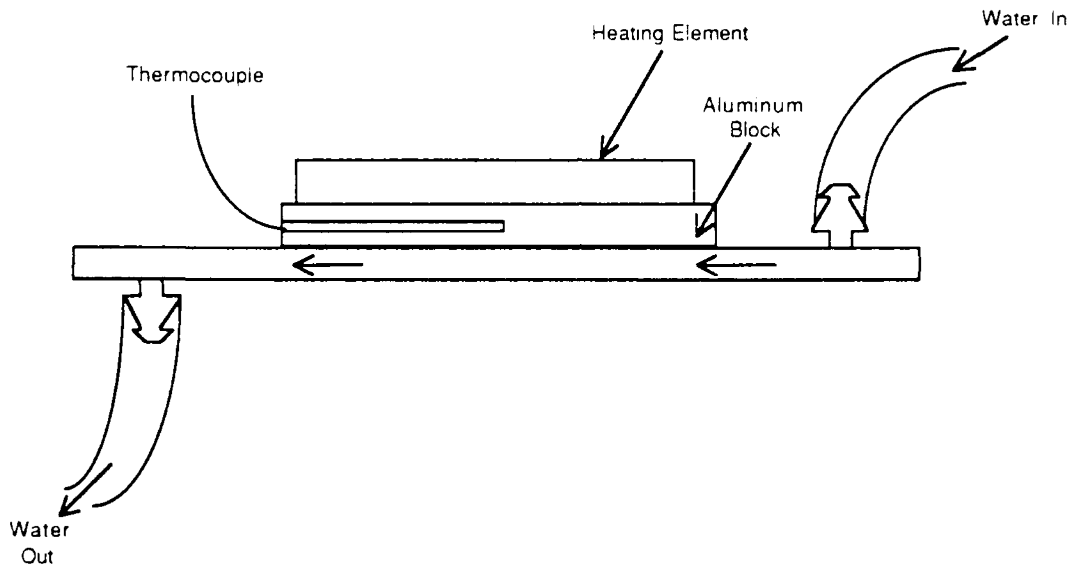

Figure #1 Side View of the LCHS Parallel to the Microchannels

Figure #2 is a top view of the ceramic plate. It is 2" x 2" x 0.01". An array of 650 0.01" diameter holes (13 columns x 50 rows) were CO_2 laser drilled into the center portion of each plate. Four 0.04" diameter alignment holes were drilled at the periphery of each plate. One hole per edge. At the proper time during processing, guide pins are inserted into an alignment fixture. The guide pins allow for a precise (± 0.001") alignment of the top and bottom plates. The 0.25" holes were drilled; one at the lower left hand side of the 650 array and the other at the upper right hand side of the array. These holes are for water input and water output.

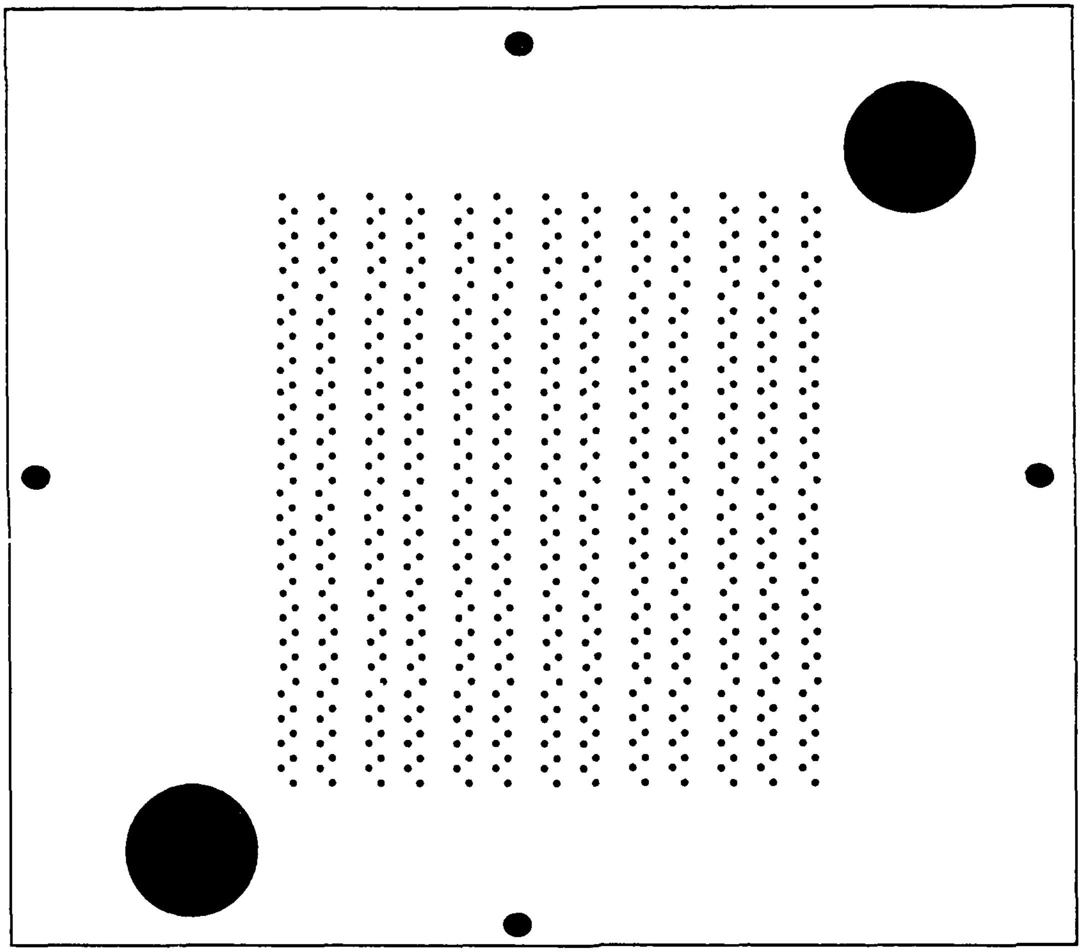

Figure #2 Top View of Ceramic Plate

Figure #3 is a side view of the LCHS perpendicular to the microchannels. The thickness of the LCHS is 35 mils; 2 x 10 mil ceramic plates plus 15 mils of E2. E2 is a proprietary polymer developed by ISA and Zeon Technology.

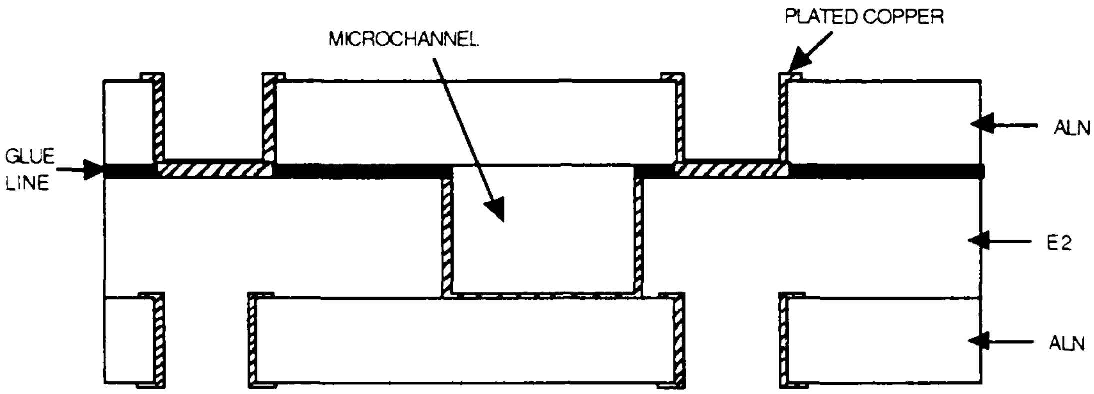

Figure #3 Side View of the LCHS Perpendicular to the Microchannels

Figure #4 is a side view of the LCHS parallel to the microchannels. Note how the electrical feedthroughs were fabricated. This is a staggered feedthrough, as opposed to a straight feedthrough. Either approach is acceptable when the aspect ratio is small. The aspect ratio is the diameter of a hole compared to the sputtering depth. The diameter of the LCHS holes are 10 mils and the depth (thickness) is 35 mils. If the straight feedthrough approach was being used the ratio would be 1:3.5. Problems with sputtering coverage on the walls of the holes will develop as the aspect ratio rises above 1:5.

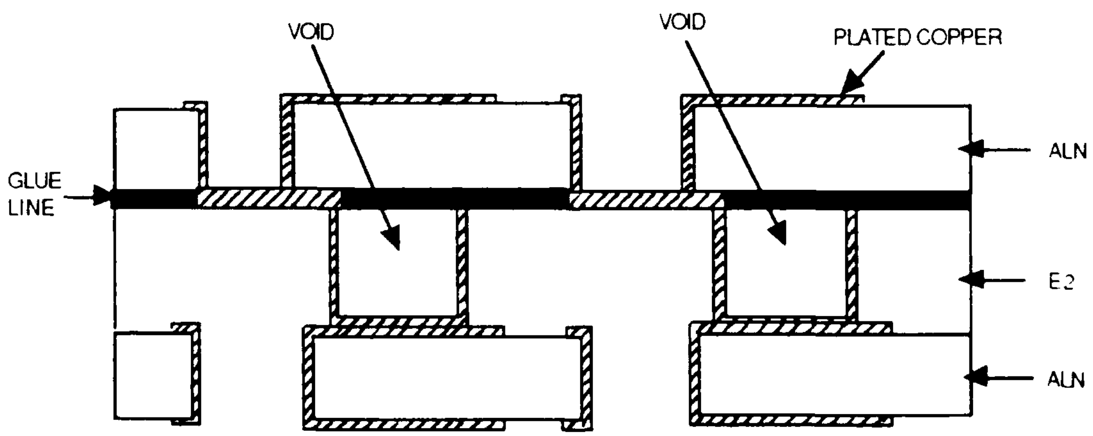

Figure #4 Side View of the LCHS Parallel to the Microchannels.

Approximately forty process steps are required to fabricate the LCHS. Copper bonds pads are plated on the front and back of the base plate. The base plate is mounted on a 2"x 2"x 2 mm quartz substrate. The quartz provides rigidity. A "quarter" sized amount of E2 is dispensed onto the quartz substrate. The base plate is gently pressed on top of the E2. A large portion of the E2 passes through the holes and onto the top of the base plate. Three grams of E2 is dispensed on the top of the base plate. The quartz substrate is placed on a 150 °C hot plate for an overnight cure. The base plate adheres to the quartz substrate as the E2 cures.

After curing, the E2 is ground to a thickness of 15 mils. The E2 is transparent. A dental pick is used to make small indentations in the E2. These indentations correspond with alignment marks on the base plate.

The part, now known as the base, is sputtered with titanium and copper. Positive acting photoresist is spin coated. A series of photolithographic and copper plating steps follow; the end result is a part with 1 mil of patterned, plated copper on the E2. The next step is to laser ablate the base. E2 which is not protected by the copper will be ablated. This is how the microchannels and the electrical vias are formed.

When ablation is complete, the plated copper and the sputtered titanium are etched. The bottom and the sidewalls of the microchannels and the vias must be copper plated. To achieve this, the base is sputtered with titanium and copper. Next, the base is "plated" with an electro-deposited photoresist. This photoresist is negative acting and is completely conformal; i.e., it deposits a dense, uniform film over horizontal as well as vertical features. A series of photolithographic and copper plating steps are performed which produces a part with copper plated microchannels and electrical vias. Bond pads which are attached to the electrical vias are plated on top of the E2. The negative acting photoresist is stripped and the sputtered copper and titanium is etched off the base.

The quartz substrate is no longer needed. It is separated from the base by way of laser ablation. The top plate needs to be attached to the base. This is done in two separate steps. First, a thin bead of thixotropic 1004 is dispensed along the perimeter of the base. The base is placed in the alignment fixture. Using the guide pins of the alignment fixture, the top plate is aligned with the base. A 2.5" x 2.5" x 0.125" piece of quartz is pressed on the top plate and held in place by a metal brace and bolts. The entire assembly is exposed to UV light (20 mW/cm^2). The thixotropic 1004 is fully cured after 30 minutes. The top plate is securely adhered to the base along the perimeter.

After curing, the LCHS (base plus top plate) is removed from the alignment fixture. The second step in the attachment process is to fill up the gap between the holes in the top plate and the copper bond pads that are attached to the electrical vias. A small syringe is filled with thixotropic 1004. Thin "lines" of 1004 are dispensed over all of the holes. A single edged razor blade is drawn across the top plate and forces the 1004 down through the holes of the top plate. A combination of the applied pressure and the wetting of both surfaces (the top of the E2 along with the copper bond pads and the bottom of the top plate) ensures that the gap between the base and the top plate is completely filled with 1004. Excess 1004 is removed and the LCHS is exposed to UV light for 30 minutes.

At this stage, the microchannels are fully functional; they are capable of carrying water. The electrical interconnection from the bottom to the top of the LCHS is not yet complete.

The cured 1004 that is in the holes of the top plate is laser ablated down to the copper bond pads. Next, the LCHS is sputtered with Ti/Cu. After sputtering, the electro-deposited photoresist is applied to the LCHS. Standard photolithographic and copper plating steps yield a part with copper bond pads on the top plate. The copper bond pads on the top plate are connected to the copper bond pads on the E2. These bond pads in turn are connected to copper bond pads on the top of the base plate. The bond pads on the top of the base plate are connected to the bond pads at the bottom of the base plate; thus, electrically connecting the top of the LCHS with the bottom.

RESULTS AND DISCUSSION

The thickness of the LCHS is 0.75 mm. It is 30% thinner than the original design goal of 1.25 mm. 100 electrical feedthroughs per square centimeter was successfully demonstrated. The goal of 50 W/cm^2 with a temperature rise of 25 °C was not achieved. A 45 °C temperature rise at 40 W/cm^2 has been observed. The water flow rate at the time of these measurements was 530 ml/minute (The LCHS has 12 microchannels each with the following dimensions: length = 1 inch, width = 0.75 mm and height = 0.38 mm).

Two reasons are given as to why the thermal performance did not meet the above stated goal. First: there was poor thermal coupling between the LCHS and the heat source. In the future, instead of using thermal paste and a C-clamp to mount the heat source to the LCHS, the heat source will be bonded to the LCHS with a thermally conductive epoxy. Second: as stated in the text, there is a two step operation to bond the top plate to the base. This two step method was not used for the LCHS that had the 45 °C temperature rise. It was discovered that the previous method of bonding forced the thixotropic 1004 into the microchannels. A cross section of a LCHS which was fabricated by the previous method showed that approximately 40% of each microchannel had been obscured by 1004. The copper plated side walls of the microchannels were insulated from the water by the 1004. This significantly reduced the heat dissipating capabilities of the LCHS.

Results of a LCHS using the two step method will be included in a later report.

It is estimated that the flow rate of water will increase from 530 ml/minute to approximately 750 ml/minute. Also, the copper plated sidewalls of the microchannels will not be isolated from the water. Both of these improvements plus the use of the thermally conductive epoxy should make it possible for the LCHS to meet its thermal design goal.

CONCLUSION

Much has been learned during the last six months of designing and processing. The current design of the LCHS has performed very well. Additional research will seek to modify and enhance the electrical and thermal performance of the LCHS. For instance, the amount of electrical feedthroughs could increase by 100%. By changing the feedthroughs from a staggered approach to a straight approach, the microchannels could be eliminated and the water could flow through an array of electrically insulated feedthroughs. It was calculated that the surface area of ceramic in contact with water would increase approximately 60% if the microchannels were eliminated. It could be argued that more heat will be conducted away from the chips as the amount of water in contact with the heated area increases.